



## Project Introduction

The Center for the Utilization of Biological Engineering in Space (CUBES) will leverage partnerships between NASA, other federal agencies, industry, and academia to: 1. Support biomanufacturing for deep space exploration; 2. Advance the practicality of an integrated, multi-function, multi-organism biomanufacturing system on a Mars mission; and 3. Showcase a continuous and semiautonomous biomanufacturing of fuel, materials, pharmaceuticals, and food in Mars-like conditions. NASA's 2015 Journey to Mars document describes the next pioneering steps in space exploration through three tiers of missions: Earth Reliant, Proving Ground, and Earth Independent. CUBES will be strategically aligned with all three tiers. A CUBES demonstration biosystem will baseline future Earth Reliant testing in 3D-printing, in situ resource utilization, and food and pharmaceutical production. CUBES research could help minimize resupply needs on a Proving Ground mission. Finally, use of the CUBES-produced biosystem to harvest Martian resources for fuel, water, oxygen, and building materials will satisfy requirements for Earth Independence. CUBES will be organized into four divisions to achieve this planned showcase. The requisite systems design and engineering efforts to optimally allocate and utilize Mars resources, tightly integrate and automate internal processes, and satisfactorily achieve biological and mechanical performance according to mission specifications will be the domain of the Systems Design and Integration Division (SDID). Activities to harness in situ resources, decontaminate and enrich regolith, and transform human and mission wastes to media and feedstocks for utilization by downstream processes will be the responsibility of the Microbial Media and Feedstocks Division (MMFD). The manufacture of propellants, biopolymers and useful chemicals from MMFD media and feedstocks along with the recycling of manufactured products at the end of their serviceable life will be tasked to the Biofuel and Biomaterial Manufacturing Division (BBMD). A key component of the BBMD-SDID interface will be the use of generated biopolymers in additive manufacturing (3D-printing). Plant and microbial engineering to realize food and pharmaceuticals for astronauts along with the recycling of plant wastes will be the focus of the Food and Pharmaceutical Synthesis Division (FPSD). The primary CUBES research objectives are: 1. In situ microbial media production, which harnesses Mars atmospheric and regolith resources for downstream biological use; 2. In situ manufacture of mission products, which creates outputs like propellants and building materials that are fundamental enablers of any long-duration space mission; 3. In situ food and pharmaceutical synthesis, which allows these long-duration space missions to be manned, and uses plants and microbes that provide food, nutrients and medicine; and 4. Space and complex systems engineering, which analyzes, guides, tests, improves, and integrates the internal processes of objectives 1-3 above. The CUBES goal of efficiently using in situ resources and effectively recycling them to drive the manufacture of useful products will meet a long-standing need for space missions, which is to substantially reduce manufacturing-infrastructure mass and related costs in harsh conditions. The



Center for the Utilization of  
Biological Engineering in Space

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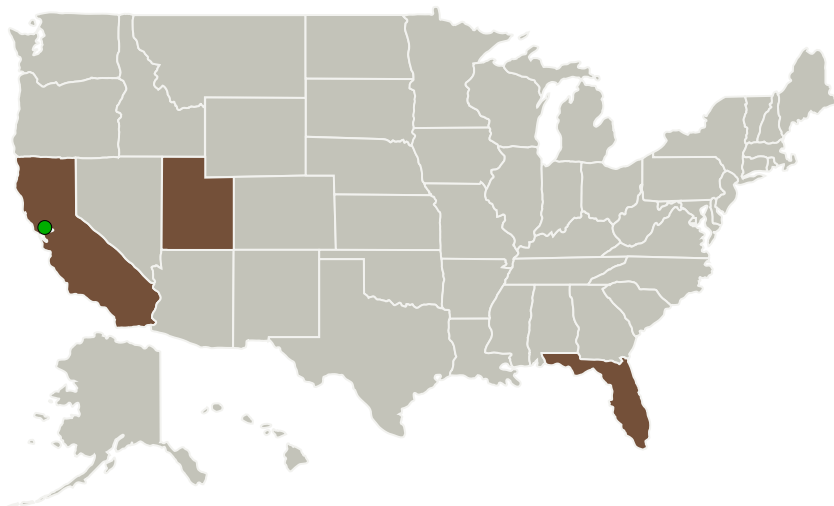


planned CUBES output of a semi-closed loop that integrates resource-recovery in a resource-poor environment with waste streams to biologically drive the manufacture of fuel, materials, pharmaceuticals, and food will establish the capacity to biologically support manned space exploration on par with abiotic techniques. CUBES benefits will include: 1. Engineered microbes to convert limited or marginally accessible Martian feedstocks, such as atmospheric gases at low partial pressure and nutrients from contaminated/toxic land, into valuable commodities. 2. Novel biologically-coupled nanotechnologies to fix available carbon and nitrogen and to transfer energy into biosynthetic processes; 3. Refined plants and plant microbiomes that grow in restricted space, light, water, and nutrients, and that can still provide substantial yields of nutritive foods; 4. Biologically-produced pharmaceuticals, cell-based treatments/therapeutics, and materials for on-demand diverse additive manufacturing applications; and 5. Optimized, integrated operation of the above processes.

### Anticipated Benefits

Engineered microbes to convert limited, marginally accessible Martian feedstocks, such as atmospheric gases at low partial pressure and nutrients from contaminated/toxic land, into commodities. Novel biologically-coupled nanotechnologies to fix available carbon and nitrogen and to transfer energy into biosynthetic processes; Refined plants and plant microbiomes that grow in restricted space, light, water, and nutrients, and that can still provide substantial yields of nutritive foods; Biologically-produced pharmaceuticals, cellular treatments/therapeutics, and materials for on demand diverse 3D-printing applications; and Optimized, integrated operation of these processes.

### Primary U.S. Work Locations and Key Partners



### Organizational Responsibility

#### Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

#### Lead Organization:

University of California-Berkeley (Berkeley)

#### Responsible Program:

Space Technology Research Grants

### Project Management

#### Program Director:

Claudia M Meyer

#### Program Manager:

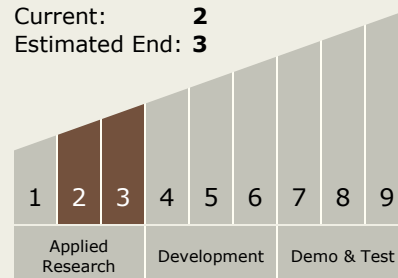
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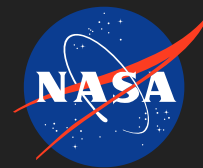
#### Principal Investigator:

Adam P Arkin

### Technology Maturity (TRL)

Start: 2  
Current: 2  
Estimated End: 3





Organizations Performing Work	Role	Type	Location
University of California-Berkeley(Berkeley)	Lead Organization	Academia	Berkeley, California
● Ames Research Center(ARC)	Supporting Organization	NASA Center	Moffett Field, California
Autodesk	Supporting Organization	Industry	
Stanford University(Stanford)	Supporting Organization	Academia	Stanford, California
University of California-Davis(UC Davis)	Supporting Organization	Academia Asian American Native American Pacific Islander (AANAPISI)	Davis, California
University of Florida	Supporting Organization	Academia	Gainesville, Florida
Utah State University(USU)	Supporting Organization	Academia Alaska Native and Native Hawaiian Serving Institutions (ANNH)	Logan, Utah

## Technology Areas

### Primary:

- TX06 Human Health, Life Support, and Habitation Systems
  - └ TX06.3 Human Health and Performance
    - └ TX06.3.7 System Transformative Health and Performance Concepts

## Target Destinations

The Moon, Mars, Others Inside the Solar System

### Primary U.S. Work Locations

California	Florida
Utah	

### Project Website:

<https://www.nasa.gov/strg#.VQb6T0jJzyE>